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JRC - Metasensing Coupled Spaceborne & Airborne SAR Campaign in Rotterdam

Results of the coupled Spaceborne & Airborne SAR Small Boat Detection campaign carried out by the EC-JRC and Metasensing in Rotterdam, The Netherlands in February 2011

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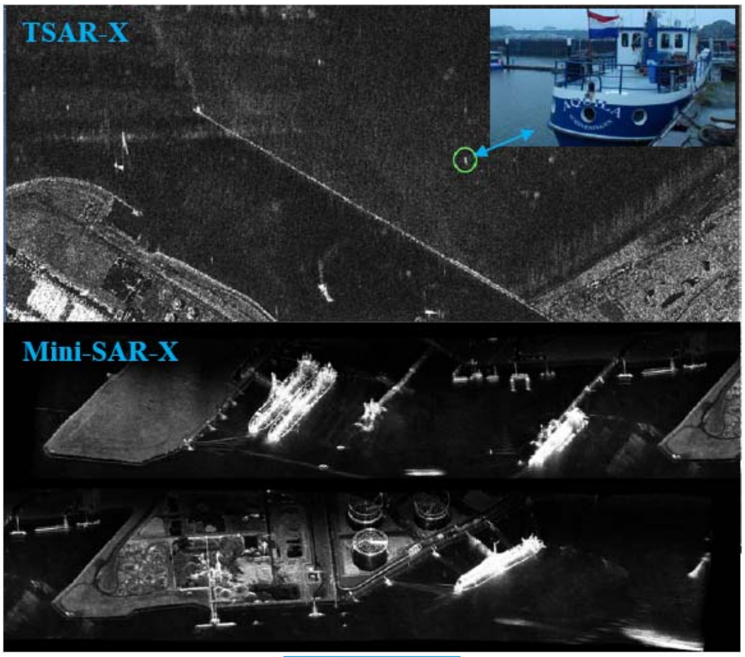
2012



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EXECUTIVE SUMMARY

The European maritime area is one of Europe's most important assets with regard to resources, security and ultimately prosperity of the Member States. A significant part of Europe's economy relies directly or indirectly on it. It is not just the shipping or fisheries industries and their related activities. It is also shipbuilding and ports, marine equipment and offshore energy, maritime and coastal tourism, aquaculture, submarine telecommunications, blue biotech and the protection of the marine environment. The European maritime area faces several risks and threats posed by unlawful activities, such as drugs trafficking, smuggling, illegal immigration, organised crime and terrorism. Piracy in international waters also constitutes a threat to Europe since it can disrupt the maritime transport chain. These risks and threats can endanger human lives, marine resources and the environment, as well as significantly disrupt the transport chain and global and local security. It is anticipated that these risks and threats will endure in the mid and long run. In order to keep Europe as a world leader in the global maritime economy, an effective integrated/interoperable, sustainable maritime surveillance system and situational awareness are needed.

A significant number of unlawful maritime activities, such as illegal immigration, drugs trafficking, smuggling, piracy and terrorism involve mainly small boats, because small boats are faster and more difficult to detect using conventional means. Hence, it is very important to find out the feasibility of using SAR Satellite imagery for small boat detection. Since 2008 the EC-JRC has carried out a number of of SAR Small Boat detection controlled experiments to assess the feasibility of using Spaceborne SAR for Small Boat detection. This report presents the results and conclusions of the coupled spaceborne SAR / Airborne SAR small boat detection campaign on coastal waters carried out by the EC-JRC in Rotterdam, The Netherlands on 28 February 2011.

The results of this coupled Spaceborne SAR / Airborne SAR small boat detection experiment show the potential of Airborne SAR for maritime surveillance is strong, in particular for small target detection and that small boat detection in spaceborne SAR is possible under suitable conditions of sea state, wind speed and incidence angle. In fact, the experiment highlights how Airborne SAR can fill in the maritime surveillance gap between ship-borne/land-based surveillance assets and spaceborne SAR. For instance, spaceborne SAR allows small boat detection under suitable sea and wind conditions. However, it neither allows classification nor identification of small boats. Airborne SAR, besides detection also allows classification and in some cases the identification of small targets. Hence, since most unlawful activities in the maritime domain, such as illegal immigration, drugs trafficking, smuggling, terrorism and piracy involve small boats, the potential of Airborne SAR for maritime surveillance is very high. Airborne SAR can use both manned and unmanned platforms. However, Before Unmanned Aircraft Systems (UAS) can be routinely used for maritime surveillance in non-segregated airspace, a significant number of key issues related to critical UAS systems have to be addressed, namely command and control issues, telecommunications (e.g. change over from Line-of-Sight (LOS) to Beyond Line-of-Sight (BLOS) Satcom), hand over of Air Traffic Control (ATC) between military and civil, collision avoidance systems, cross-border issues, flight plan modifications, contingency procedures, legal framework and regulations, etc.. Other interesting lines of research are UAS formation flying issues, patterns for optimal surveillance, onboard data fusion, full autonomy and endurance and altitude issues.

1. – Introduction

1.1 – Scope

This report presents the key findings of the coupled Spaceborne SAR / Airborne SAR Small Boat Detection Campaign, led by the EC-JRC and conducted jointly with Metasensing in Rotterdam, The Netherlands in February 2011.

This study addresses the potential of Airborne Mini-SAR for maritime surveillance and the feasibility of using UAS carrying a Mini-SAR as a complementary technology on an operational basis.

To answer this statement of work, a multinational cross-disciplinary consortium with research and operational expertise in maritime surveillance and Airborne SAR was assembled with organisations involved in:

1.- research in maritime surveillance using Spaceborne SAR imagery and in the processing and analysis of SAR imagery, as well as coordination and management of maritime surveillance campaigns (European Commission-JRC).
2.- experience with Airborne SAR campaigns (Metasensing).

1.2 – Main Objectives

The work was performed with the following main objectives:

- To acquire hands-on experience with Airborne Mini-SAR technologies, in particular with its possible applications to maritime surveillance.

- To assess the potential of Airborne SAR for maritime surveillance, including small boat detection, illegal immigration and drugs trafficking mitigation.

- To study the feasibility of using UAS as a complementary maritime surveillance technology on an operational basis together with currently used technologies.

- To identify the main limiting factors preventing the use of UAS and enabling factors that could help to facilitate the operational use of UAS for maritime surveillance.

1.3 – Context

Problem Statement – The European maritime area is one of Europe's most important assets with regard to resources, security and ultimately prosperity of the Member States. A significant part of Europe's economy relies directly or indirectly on it. It is not just the shipping or fisheries industries and their related activities. It is also shipbuilding and ports, marine equipment and offshore energy, maritime and coastal tourism, aquaculture, submarine telecommunications, blue biotech and the protection of the marine environment. The European maritime area faces several risks and threats posed by unlawful activities, such as drugs trafficking, smuggling, illegal immigration, organised crime and terrorism. Piracy in international waters also constitutes a threat to Europe since it can disrupt the maritime transport chain. These risks and threats can endanger human lives, marine resources and the environment, as well as significantly disrupt the transport chain and global and local security. It is anticipated that these risks and threats will endure in the mid and long run. In order to keep Europe as a world leader in the global maritime economy, an effective integrated/interoperable, sustainable maritime surveillance system and situational awareness are needed.

A significant number of unlawful maritime activities, such as illegal immigration, drugs trafficking, smuggling, piracy and terrorism involve mainly small boats, because small boats are faster and more difficult to detect using conventional means. Hence, it is very important to find out the feasibility of using Airborne SAR and Unmanned Aerial Systems (UAS) on an operational basis as a complementary maritime surveillance technology to currently used maritime surveillance assets, such as spaceborne SAR, coastal radars, ship-borne radars, etc.

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2. – Research Method

In order to find out the potential and feasibility of using Airborne SAR / Unmanned Aircraft Systems (UAS) for maritime surveillance, including small boat detection, a controlled experiment on coastal sea waters was designed, set up and executed. The controlled experiment is briefly described next.

The controlled experiment was initially planned to comprise two steps: first, the deployment of a small boat near the port of Rotterdam, and second, the simultaneous acquisition of a spaceborne SAR image and Mini-SAR image using a UAS. Due to technical problems it was not possible to use a UAS. A light Cessna aircraft was used to replace the UAS. Due to bad weather conditions the Cessna was not authorized to takeoff to acquire data at the approximate time of the SAR satellite overpass.

The experiment was divided into two experiments:

1.) A first experiment which comprised the deployment of a small boat near the port of Rotterdam at the approximate time of a SAR satellite overpass (TerraSAR-X), and
2.) A second experiment comprising the acquisition of Mini-SAR data over the port of Rotterdam using a Cessna aircraft.

2.1 – Controlled Experiment on Coastal Waters

The main objective of this controlled experiment was to find out the potential of using Airborne SAR and UAS for maritime surveillance along the coast. The main purpose behind it was to test the capabilities of Airborne SAR and UAS to detect, classify and identify targets on sea. To that end, A small boat was deployed near the port of Rotterdam and a spaceborne SAR image of the area acquired. This was followed by data acquisition over the same area using a Mini-SAR carried by Cessna aircraft.

3. – Experiment Set Up

In this section we describe the experiment set up, namely the experiment site selection, the SAR Satellite Imagery planning and the partners involved and their roles.

3.1 – Experiment Site Selection

The site for this experiment was selected based on practical considerations about the expected outcome of the experiment and its feasibility, including the number of boats that could be detected, the authorization to fly a UAS or a light aircraft and logistics challenges. Several sites have been shortlisted. After a careful analysis of the advantages and disadvantages of all possible sites and the inputs from the Civil Aviation Authorities it was decided to carry out the experiment in Rotterdam, near the port of Rotterdam.

3.1.2 – Site Along the Coast in Rotterdam-Netherlands

The selected area for the controlled experiment was the port of Rotterdam. Figure 1 gives an overview of the port of Rotterdam.

Figure 1 – Overview of the site of the experiment, the port of Rotterdam, and the footprint of the Spaceborne SAR image. The footprint is indicated by the four corners of the rectangle (4 green Pins).

3.3 – SAR Satellite Imagery Planning

Figures 3 and 4 illustrate the spaceborne SAR imagery planning. The footprints of the SAR Satellite images selected are shown in the google earth image of the region of Porto Corallo, Sardinia, Italy.

The Synthetic Aperture Radar (SAR) satellite imagery available at the time the planning was done comprised Radarsat2 (Spotlight and Ultrafine) and TerraSAR-X (Spotlight and Stripmap). Figure 3 illustrates the Radarsat2 images available. Table-1 illustrates the SAR satellite images and image modes used in the different days of the experiment.

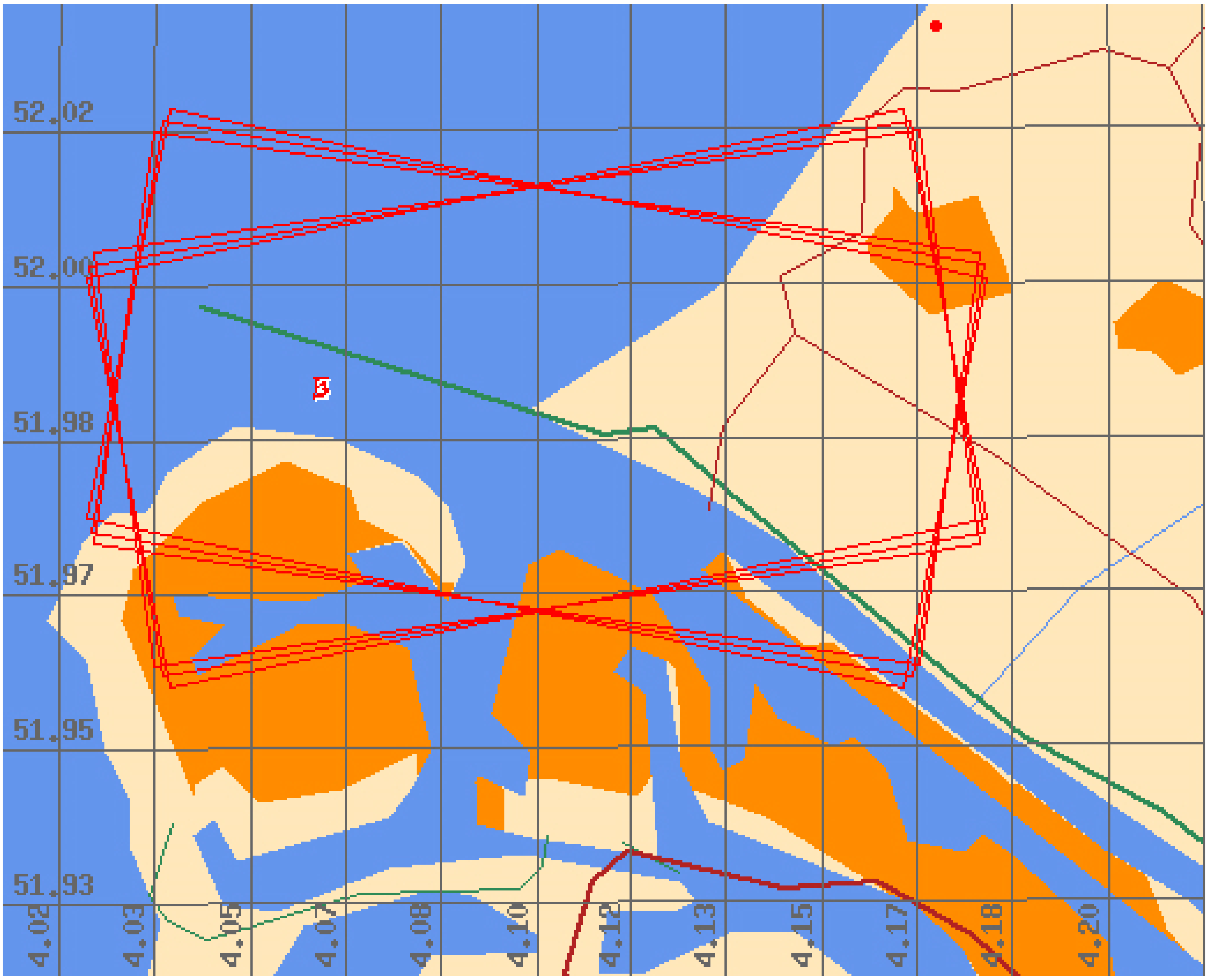

Figure 2 – TerraSAR-X / Spotlight High Resolution frames over the port of Rotterdam in the Netherlands. The rectangles in red are the footprints of the TerraSAR-X-Spotlight High Resolution SAR images available in the period between 20Feb.-28Feb. 2011. The frames are 10km x 5km. The dates and times are given bellow in Table-1.

Table 1- TerraSAR-X, Spotlight SAR images available from 20Feb.-28Feb.2012.

#	Morning Satellite Pass	Evening Satellite Pass
1	Start Date: 2011-02-20T05:51:12.632 - DES End Date: 2011-02-20T05:51:12.632 - DES	
2		Start Date: 2011-02-22T17:35:16.911 - ASC End Date: 2011-02-22T17:35:16.911 - ASC
3		Start Date: 2011-02-23T17:18:09.735 - ASC End Date: 2011-02-23T17:18:09.735 - ASC
4	Start Date: 2011-02-25T05:59:46.806 - DES End Date: 2011-02-25T05:59:46.806 - DES	
5		Start Date: 2011-02-28T17:26:42.876 - ASC End Date: 2011-02-28T17:26:42.876 - ASC

The SAR image selected for the experiment was the image of 28 Feb. 2012.

3.4 – Review of the Spaceborne SAR Imagery modes available

The Radarsat2 and TerraSAR-X image modes used in the present experiment will be briefly reviewed in the next paragraphs.

Radarsat2 - Spotlight Mode – The Spotlight Beams are intended for applications which require the best spatial resolution available from the RADARSAT-2 SAR system. In this mode the radar operates with the highest sampling rate, and so the ground swath coverage is limited to keep data rate within the recorder limits. Unlike the other modes, Spotlight images are also of fixed size in the along track direction.

The ser of Spotlight Beams cover any area within the incidence angle range from 20 to 49 degrees. Each beam within the set images a swath width of at least 18 km. Spotlight images can only be generated in a single polarization, which can be either a linear co-polarization (HH or VV) or a linear cross-polarization (HV or VH).

Radarsat2 - Single Beam Mode – Single beam mode is a stripmap SAR mode. In Single Beam operation, the beam elevation and profile are maintained constant throughout the data collection period. The following Single Beam modes are available: Standard, Wide, Fine, Multi-Look Fine, Ultra-Fine, Extended High (High Incidence), Extended Low (Low Incidence), Standard Quad Polarization and Fine Quad Polarization. We selected Ultra-Fine because it is the best compromise between swath coverage and resolution.

Radarsat2 - Ultra-Fine – The Ultra-Fine Resolution Beams are intended for applications which require very high spatial resolution. In this mode the radar operates with the highest sampling rate, and so the ground swath coverage is limited to keep data rate within the incidence angle from 20 to 49 degrees. Each beam within the set images a swath width of at least 20 km. Ultra-Fine Resolution images can only be generated in a single cross-polarization , which can be either a linear co-polarization (HH or VV) or a linear cross-polarization (HV or VH).

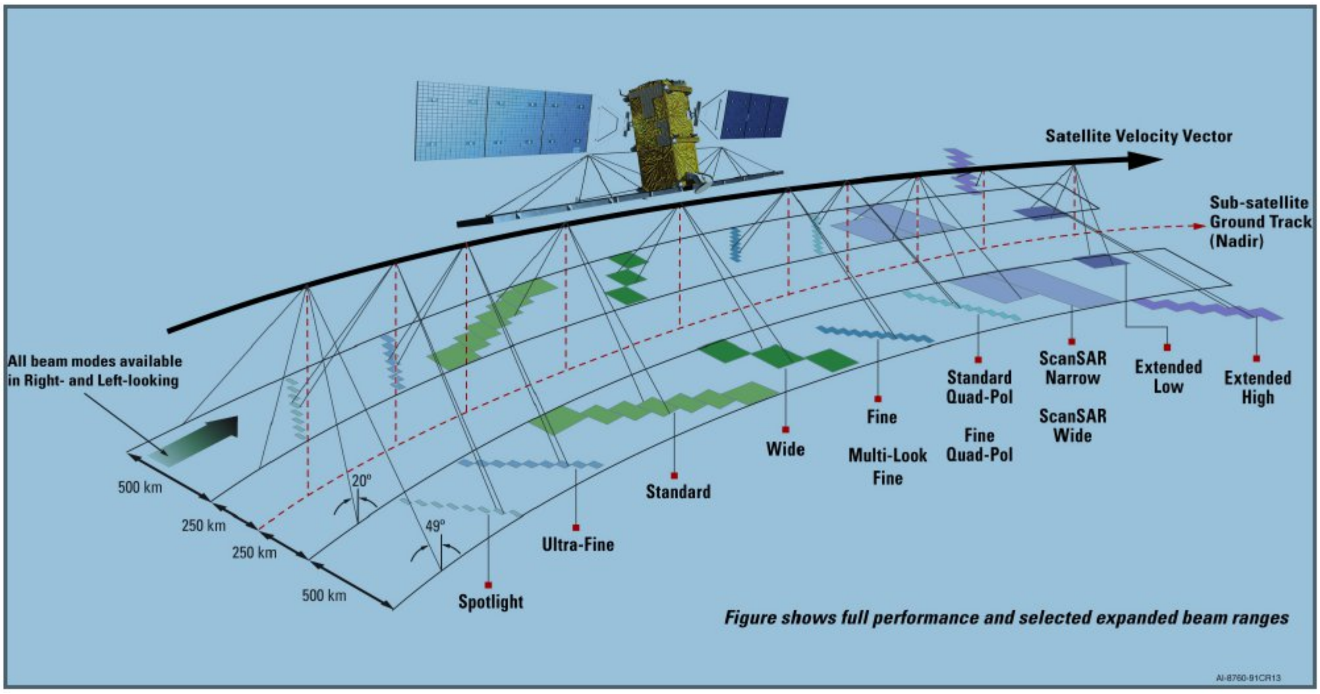

Figure 3 – Radarsart2 image modes. The Ultrafine and the Spotlight modes have been identified as the most suitable modes for this particular experiment.

The **standard TerraSAR-X operational mode** is the single receive antenna mode from which the following imaging modes can be retrieved: High Resolution Spotlight and Spotlight, StripMap, and ScanSAR. The single receive antenna mode uses a chirp
bandwidth of up to 300 MHz.

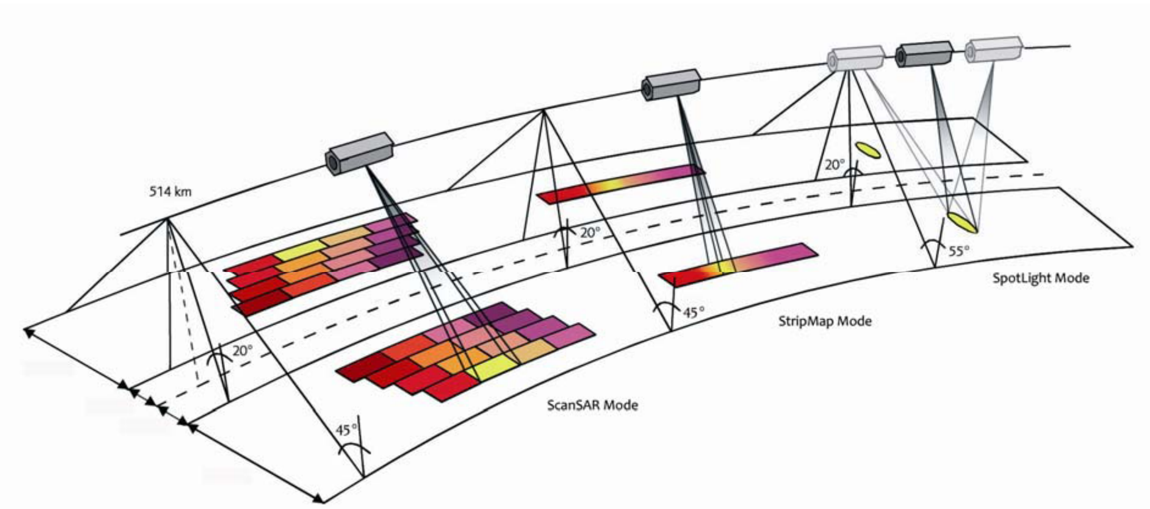

Figure 4 – Radarsart2 image modes. The Ultrafine and the Spotlight modes have been identified as the most suitable modes for this particular experiment.

The **SpotLight (SL)** imaging modes use phased array beam steering in azimuth direction to increase the illumination time, i.e. the size of the synthetic aperture. This leads to a restriction in the image / scene size. Thus, the scene size is technically restricted to a defined size: 10 km x 10 km for the SpotLight mode and 10 km x 5 km (width x length) in the HighResolution SpotLight (HS) mode.

This sophisticated imaging mode makes it possible to acquire data with up to 1 m resolution in the HighResolution SpotLight mode (acquired with a bandwidth of 300 MHz) and 2 m in the standard SpotLight mode.

StripMap (SM) is the basic SAR imaging mode as known e.g. from ERS-1 and other radar satellites. The ground swath is illuminated with continuous sequence of pulses while the antenna beam is fixed in elevation and azimuth. This results in an image strip with a continuous image quality (in flight direction). StripMap dual polarisation data have a slightly lower spatial resolution and smaller swath than the single polarisation data.

In StripMap mode, a spatial resolution of up to 3 m can be achieved. The standard scene size is 30 km x 50 m (width x length) in order to obtain manageable image files; however, acquisition length is extendable up to 1,650 km.

The spaceborne SAR image selected was a TerraSAR-X-Spotlight acquired on 28 Feb.2011 by 17:26:42 UTC. Table 2 gives the basic characteristics of the SAR image.

Table 2 – Spaceborne SAR image acquired over Porto Corallo, Sardinia, Italy.

Date/Time	Area	Satellite / Mode	Polarization	Pass
28.Feb. 2011 (PM) T17:26:42.876	Rotterdam-The Netherlands	TerraSAR-X / Spotlight	HH	Ascending

3.4 – Partners Involved and their Roles

The partners involved in this experiment comprised the European Commission (EC) – Joint Research Centre (JRC). The role of each partner is briefly described next.

3.4.1 - European Commission (EC) – Joint Research Centre (JRC)

– The main role of the EC-JRC was the planning, set up, execution and the analysis of the data together with Metasensing. This comprised:

a.) the definition of the objectives,
b.) the research methods used,
c.) the ground truth data collection,
d.) the analysis of the data and the conclusions of the experiment.

3.4.2 – Metasensing.

– The main role of Metasensing comprised:

a.) the deployment and operation of the boat used as target.
b.) the deployment and operation of the Mini-SAR.
c.) the contacts with the Dutch authorities, to obtain all required authorisations.
d.) the collection of ground truth data.
e.) The analysis of the data and conclusions of the experiment.

4. – Experiment Execution

4.1 – Modus Operandi

The modus operandi in this trial was as follows:

1.- JRC supplied Metasensing with the footprint (frame) of the spaceborne SAR image to be acquired (TerraSAR-X-Spotlight), as well as the time of the SAR satellite pass.

2.- A 20-meter boat was deployed near the port of Rotterdam with two mebers of staff, one from the EC-JRC (Victor Silva) and one from Metasensing (Adriano Meta) to collect ground truth data and make sure that the boat was actually deployed on the right location.

3.- The boat left from the port of Scheveningen - Den Haag towards the port of Rotterdam about 2 hours before the SAR Satellite pass. The entire GPS trajectory of the boat from the port of Schveningen to the port of Rotterdam and back is illustrated in figure 6, in Blue.

4.2 – Ground Truth Data Collection

The ground truth data collected comprised:

a.) the sea state.
b.) Data from the Airborne sensors.
b.) the weather conditions and wind speed.
e.) Photos and movies of the boat involved in the experiment.
f.) GPS coordinates of the trajectory of the Boat deloyed.

4.3 – Means Involved in the Experiment

The means involved in the experiment comprised a spaceborne SAR image (TerraSAR-X-Spotlight), 1 boat (a 20-meter boat) and a Cessna carrying a Mini-SAR.

4.3.1 – Boat Deployed During the Experiment

Figure 5 illustrates the boat deployed as a target during the experiment.

Figure 5 – The 20-meter boat moored at Den Haag Scheveningen Marina before the deployment.

Figure 6 – GPS trajectory of the Boat deployed (Aquila) from the port of Schveningen to the port of Rotterdam and back. The 4 Green Pins indicate the corners of the SAR image footprint. The Pink Pin indicates the exact position of the Boat.

4.3.2 – UAS / Cessna Deployed by Metasensing

Figure 7 illustrates the Cessna deployed by Metasensing to replace the Rotorcraft. It also shows the Rotorcraft, the Mini-SAR and the two swaths of Mini-SAR data acquired during the experiment. The Mini-SAR is relatively light (about 20kg). It can be easily adjusted to most airborne systems, both manned and unmanned.

Figure 7– On the top left, the Unmanned Rotorcraft that was supposed to be deployed by Metasensing and was not deployed due to technical problems. On the top right, the Cessna deployed by Metasensing to replace the Rotorcraft The main payload was a high resolution Mini-SAR developed by Metasensing. On the bottom left, a photo of the Mini-SAR. On the bottom right, an overview of the area of the experiment at the port of Rotterdam in the Netherlands, including the two stripes of Mini-SAR data acquired..

Figure 8 shows a more detailed view of the area of the experiment with the two Mini-SAR swaths acquired during the experiment. As it can be seen the two swaths are in the footprint of the SAR satellite image. The acquisition of the spaceborne and airborne SAR images was supposed to be simultaneous, so that the Airborne images could be used as ground truth data of the spaceborne image. Unfortunately, due to bad weather conditions it was not possible. The Spaceborne SAR image was acquired on 28 Feb. 2012 and the Airborne Mini-SAR swaths were acquired the day after.

Since the Mini-SAR can be easily adjusted to an unmanned airborne system, the results of the present experiment can be extrapolated to unmanned platforms, at least to some extent if the main differences between manned and unmanned platforms are carefully observed and taken into account.

5. – Preliminary Data Analysis

5.1 – SAR Satellite Imagery Processing

The high resolution spaceborne SAR image was analysed visually, since the resolution is good enough to allow visual analysis and the site it is too close to the coast, which makes automatic processing more difficult and prone to error due to artefacts caused by land targets.

The Mini_SAR images were also analysed visually.

5.2 – Ground Truth Data

This section briefly describes the Ground Truth data, namely the GPS positions of the boats deployed as targets during the experiment, photos of the boats, as well as other relevant ground truth data collected, including the weather conditions.

5.2.1 – GPS coordinates of the boat deployed

Tables 3 gives the GPS coordinates of the boat deployed during the experiment.

Table 3 – Ground Truth data collected during the experiment on 28 February 2011.

Date: 28.Feb.2011 **Time: 17:26:42.876 UTC - / Pass: Ascending**		**Satellite/Mode: TerraSAR-X / Spotlight** **Polarisation : HH**	
Boats	**Type / Size**	**Latitude**	**Longitude**
20-meter Rubber Boat		**51.994°N**	**04.083°E**

5.2.1 – Mini-SAR Data

Figure 8 shows a more detailed view of the area of the experiment with two of the Mini-SAR swaths acquired during the experiment.

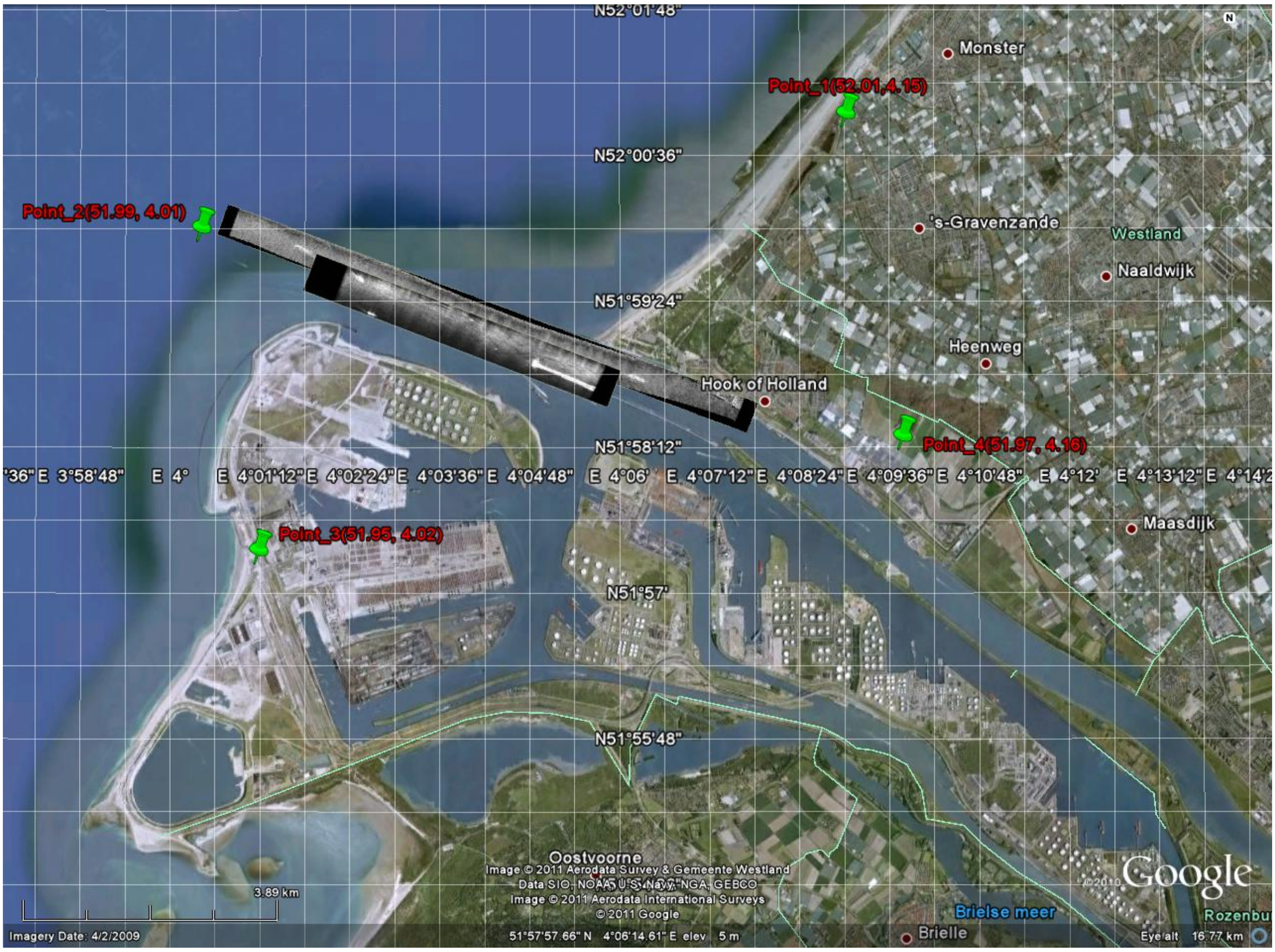

Figure 8– Area of the experiment with two of the Mini-SAR swaths acquired during the experiment over the port of Rotterdam in the Netherlands.

Figure 9 shows another google earth image with a third Airborne Mini-SAR swath. more detailed view of the area of the experiment with two of the Mini-SAR swaths acquired during the experiment.

Figure 10 shows another google earth image with a zoom in on the third Airborne Mini-SAR swath acquired during the experiment over the port of Rotterdam.

Figure 9– Area of the experiment with two of the Mini-SAR swaths acquired during the experiment over the port of Rotterdam in the Netherlands.

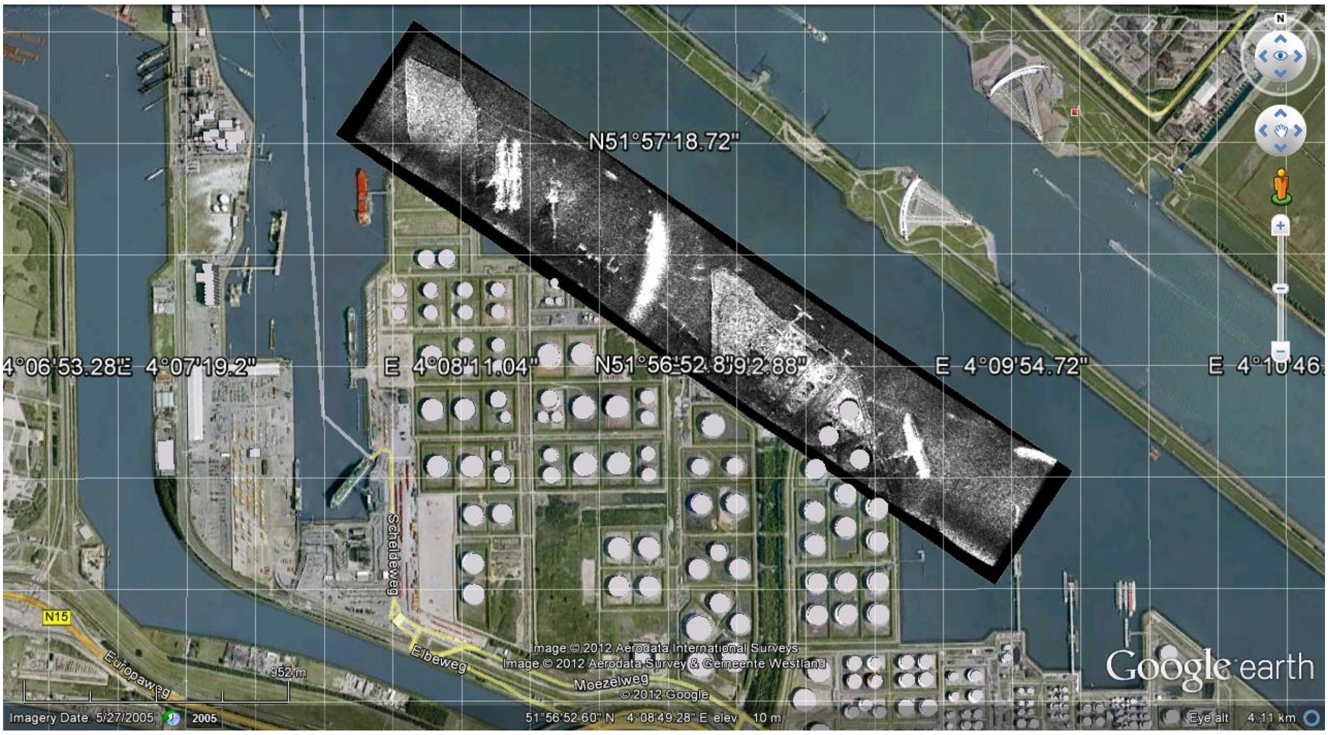

Figure 10– Google earth image of the area of the experiment showing a zoom in on one of the Mini-SAR swaths acquired during the experiment over the port of Rotterdam in the Netherlands.

5.3 – Weather Conditions and Sea State

The weather conditions in Porto Corallo are summarized in Table 4 bellow.

Table 4 – Wind speed, wind direction, Temperature and other relevant parameters.

Time (IST)	Temp.	Dew Point	Humidity	Pressure	Visibility	Wind Dir	Wind Speed	Gust Speed	Precip	Events	Conditions
6:25 PM	4.0 °C	3.0 °C	93%	1029 hPa	2.0 km	NE	14.8 km/h / 4.1 m/s	-	N/A	-	Mostly Cloudy

Figure 11 gives the weather data (Temperature, Barometric Pressure, Wind Speed and Wind Direction) for Rotterdam, The Netherlands on 28 Feb. 2011.

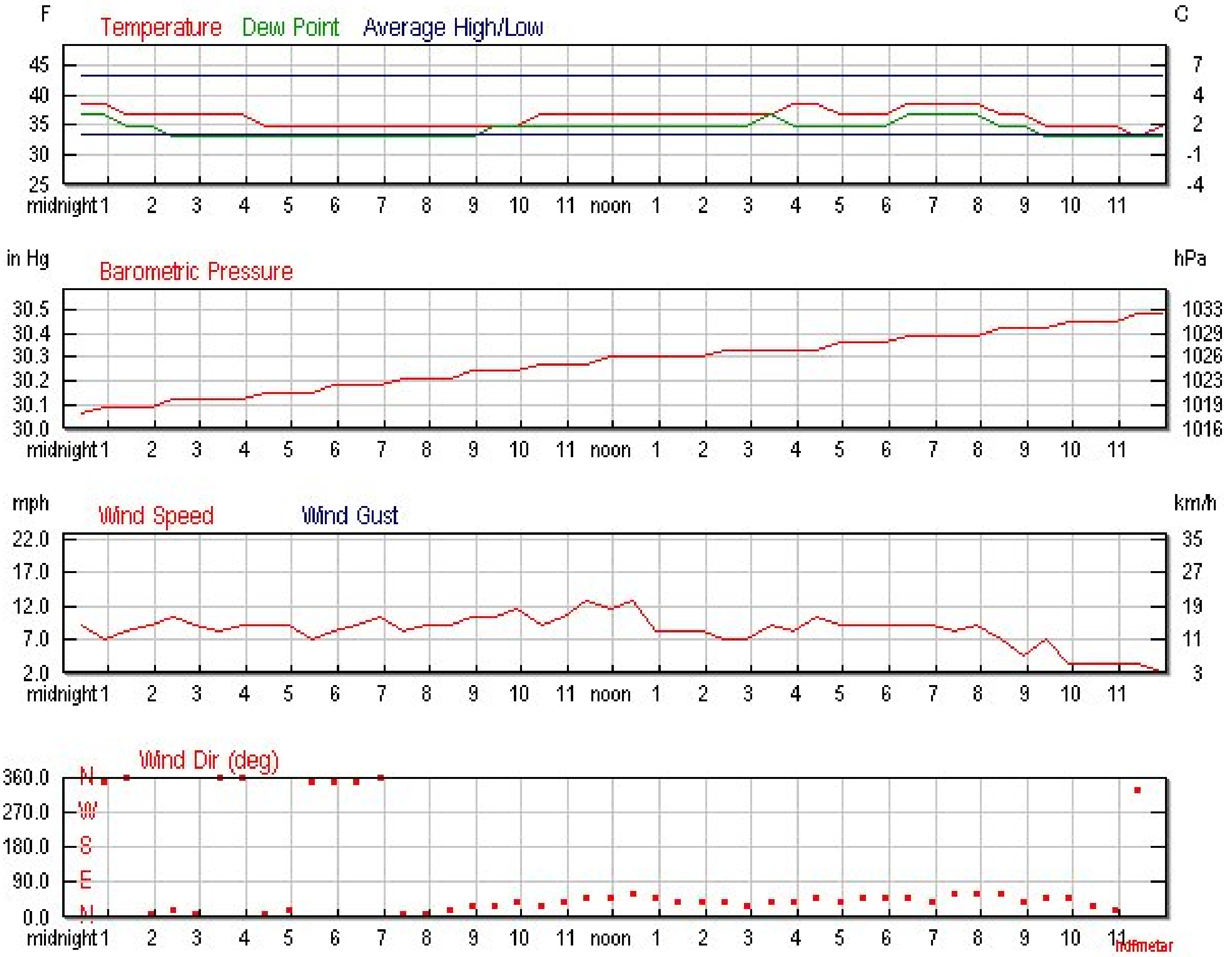

Figure 11 – Weather data (Temperature, Barometric Pressure, Wind Speed and Wind Direction) in Rotterdam, The Netherlands on 28 Feb. 2011.

The sea state was very rough as illustrated by the sequence of photos taken during the mission and presented next in figure 12. Despite of the very rough sea state the boat was detected in the TerraSAR-X, Spotlight image acquired during the experiment. The initial plan was to acquire Airborne Mini-SAR images at the approximate time of the SAR satellite overpass. Unfortunately, due to the limited visibility and wind speed the Cessna was not authorized to takeoff. The acquisition of Airborne Mini-SAR data took place the day after over the port of Rotterdam. The Mini-SAR swaths acquired are illustrated in figures 8-10 and the visual analysis of the data will be addressed in the next section.

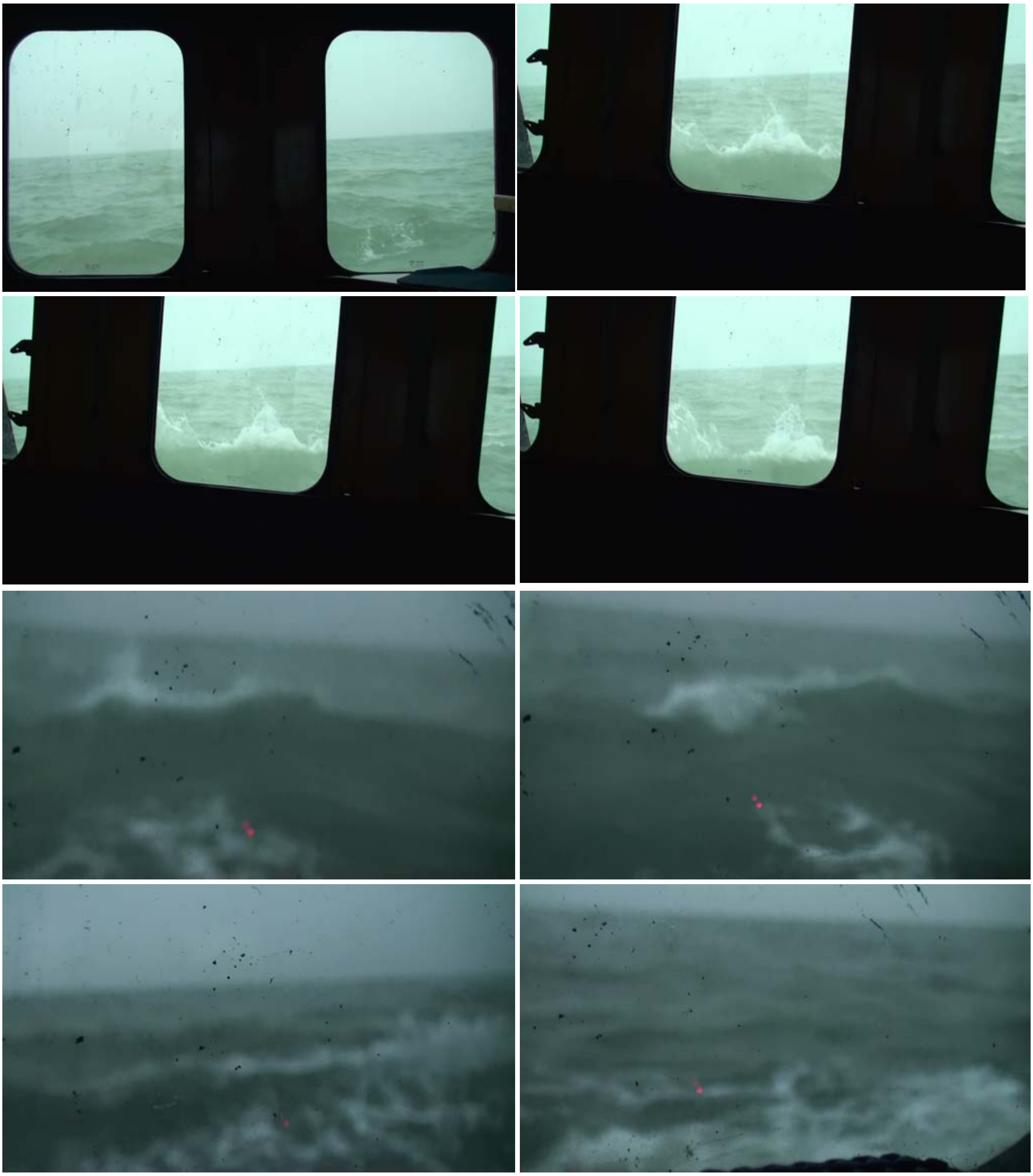

Figure 12 – Photos of the sea during the mission. As it can be seen the sea state was very rough.

5.4 – Verification of the Results

This section briefly describes the verification of the targets detected in the spaceborne SAR image and in the Airborne Mini-SAR swaths over the port of Rotterdam in The Netherlands using the ground truth data collected during the experiment.

5.4.1 – Targets Detected in the TerraSAR-X-Spotlight Image

Figure 13 gives an overview of the area of the experiment. The 4 Green Pins are the corners of the spaceborne SAR image footprint. The Blue line illustrates the GPS trajectory of the boat deployed from the port of Schveningen in the Hague to the port of Rotterdam. The Pink Pin gives the exact GPS position of the boat deployed at the time of the satellite overpass.

Figure 13 – Google Earth image of the area of the experiment. The 4 Green Pins indicate the footprint of the TerraSAR-X, Spotlight image acquired on 28Feb.2011. The line in Blue indicates the GPS trajectory of the Boat deployed from the port of Schveningen to the port of Rotterdam and back. The Pink Pin indicates the exact GPS position at the time of the satellite overpass.

Figure 14 is a subset of the TerraSAR-X, Spotlight High Resolution image acquired over the port of Rotterdam during the experiment. The Green circle indicates the SAR signature of the boat deployed (AQUILA). The SAR signature is relatively strong and does not show any smearing or any other artefacts. Given the rough sea state it would be normal to show some smearing or other artefacts.

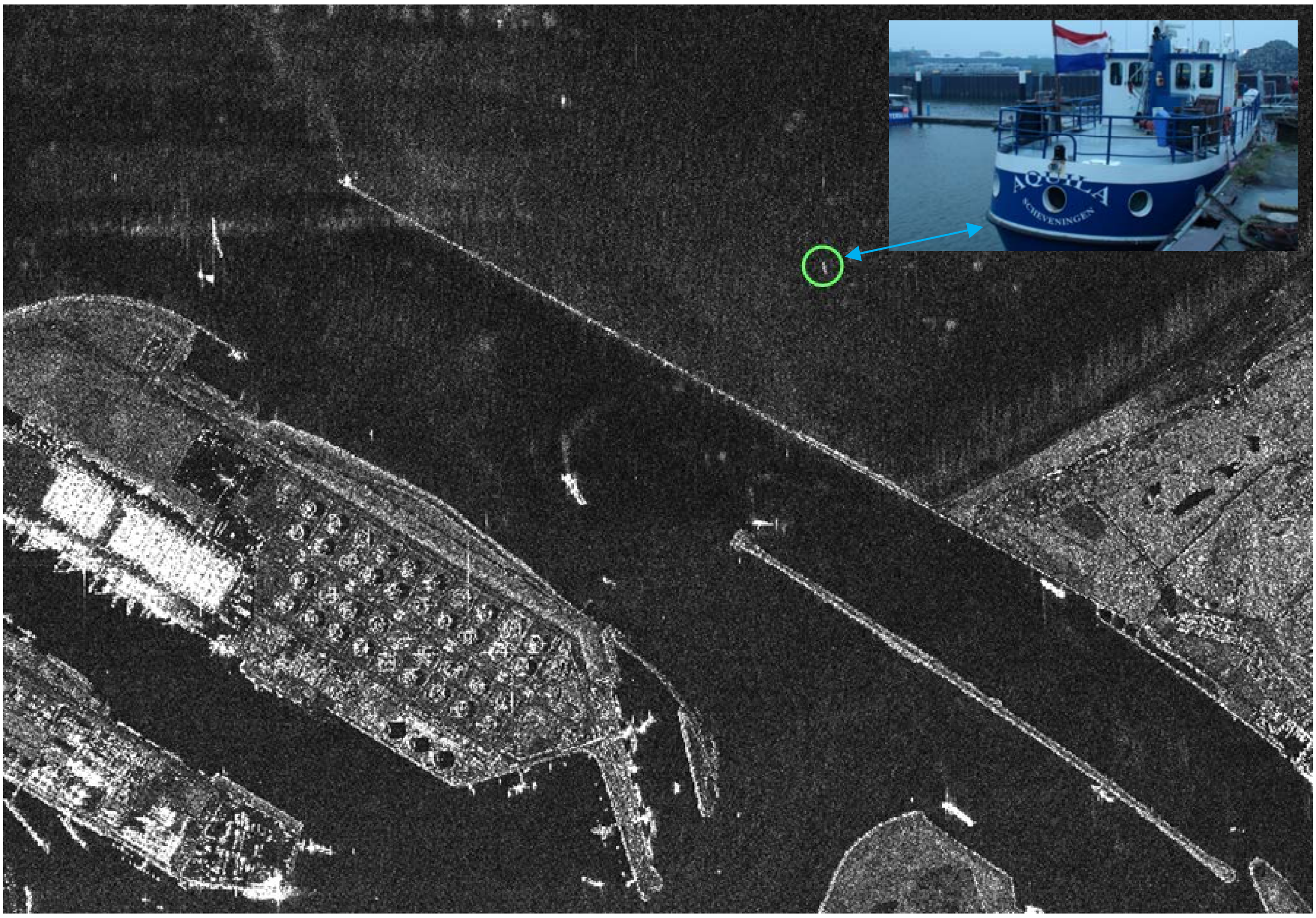

Figure 14 – Subset of the TerraSAR-X, Spotlight image acquired on 28Feb.2011 during the experiment over the port of Rotterdam in The Netherlands. The image shows several targets of different sizes. The Green circle indicates the SAR signature of the Boat deployed during the experiment, “AQUILA”.

This experiment indicates that spaceborne SAR can successfully be used for maritime surveillance to detect targets of the size and characteristics of the boat deployed even with rough sea states. The Airborne Mini-SAR swaths will be analysed in the next section.

5.4.2 – Targets Detected in the Airborne Mini-SAR Swaths

The two Airborne Mini-SAR swats acquired over the port of Rotterdam are illustrated in figure 15. The 4 Green Pins are the corners of the spaceborne SAR image footprint acquired the day before.

Figure 15 – Area of the experiment with two Mini-SAR swaths acquired during the experiment.

Figure 16 illustrates two Airborne Mini-SAR swaths acquired over the port of Rotterdam. The first swath is the one on the top of the figure. The two images in the centre are subsets of the first swath zoomed in. As it can be seen these Mini-SAR images have a very high resolution. They are particularly suitable for the detection of small targets. The second Mini-SAR swath is on the bottom of figure 16.

Figure 17 shows a zoomed in subset of one of the swaths. This zoomed in subset illustrates the very high resolution of the Mini-SAR and the high potential for the detection of small targets- An important characteristic of the Mini –SAR imagery is that it can operate in 24/7 regardless of weather conditions, except for strong winds or low visibility.

Figure 16 – On the top, a Mini-SAR swath with a large number of targets. On the centre, two subsets of the swath on the top zoomed in. As it can be seen, the Mini-SAR images have a very high resolution. On the bottom, a second Mini-SAR swath

Figure 17– Subset of one of the Mini-SAR swats zoomed in. This zoomed in subset shows the very high resolution of the image.

5.4.3 – Mini-SAR Operational Limitations

The use of the Mini-SAR for maritime surveillance is mainly limited by the weather conditions. The Mini-SAR has to be carried by an airborne platform, which can be a manned or unmanned aircraft. This type of airborne platforms can only fly under suitable weather conditions of wind speed and visibility and weather in general.

5.5 – Quantitative Analysis of the Spaceborne SAR Image

In order to allow a quantitative analysis of the data, the spaceborne SAR image was calibrated using ESA's NEST software package, version 4B. The input was the SAR image acquired and the output was the Radiometric Calibration (Sigma Naught ($\sigma°$)) expressed in terms of intensity and in decibel (dB), the Radar Brightness ($\beta°$) and the Radiometric Normalisation (gamma naught ($\gamma°$)).

5.5.1 – TerraSAR-X-Spotlight, 28Feb.2011 (17:26:42.876 UTC - / Pass: Ascending UTC), Rotterdam-The Netherlands.

Figure 18 illustrates the Intensity band of a subset of the TerraSAR-X-Spotlgiht image (28Feb.2011).

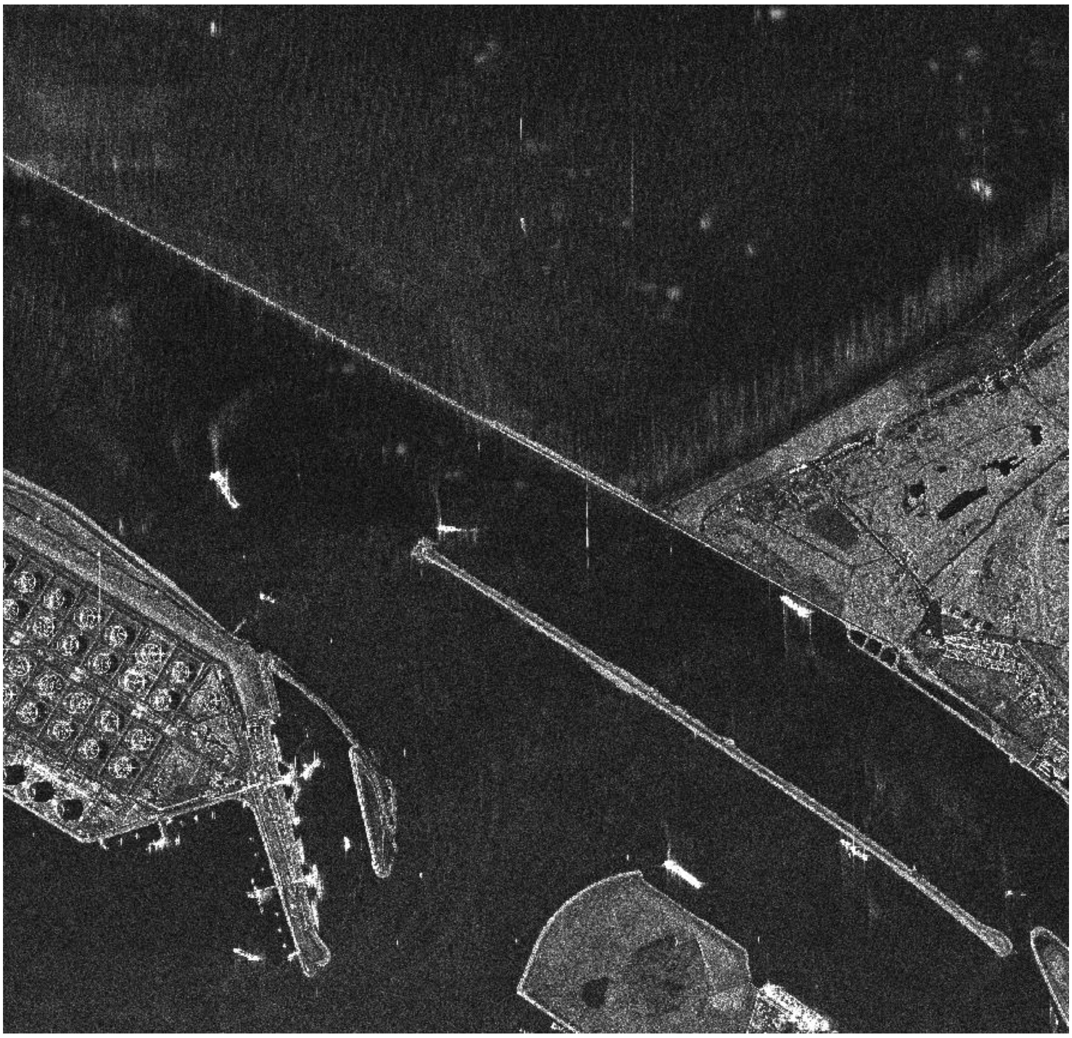

Figure 18 – TerraSAR-X-Spotlgiht image (28Feb.2011) –Amplitude band.

Figure 19 illustrates the Sigma Naught Coefficient of the TerraSAR-X-Spotlgiht image (28Feb.2011) expressed in terms of intensity and decibel (dB).

Figure 19 – TerraSAR-X-Spotlgiht image (28Feb.2011) - On the left, the Sigma Naught (σ°) (intensity) and on the right, the Sigma Naught (σ°) (dB).

Figure 20 illustrates the Radar Brightness (Beta Naught (β°)), and the radiometric normalisation (Gamma Naught (γ°)) of the TerraSAR-X-Spotlgiht image (28Feb.2011) expressed in dB.

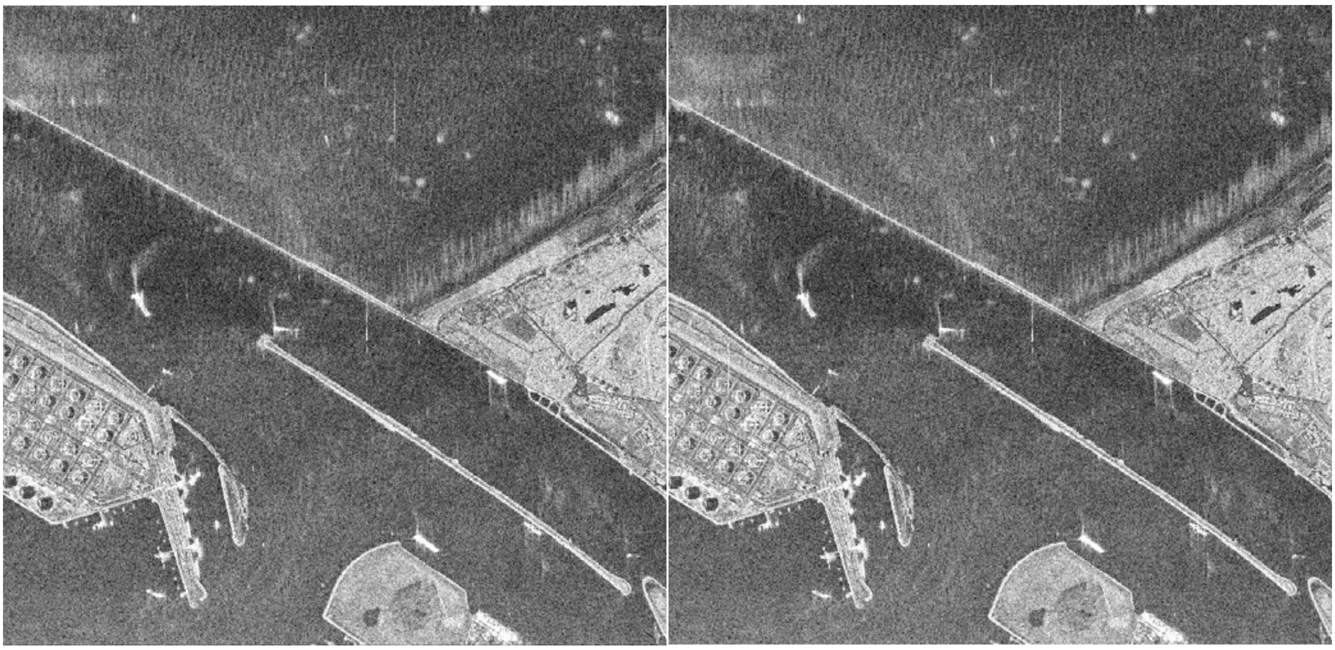

Figure 20 – TerraSAR-X-Spotlgiht image (28Feb.2011) - On the left, the Beta Naught (β°) and on the right, the Gamma Naught (γ°) (dB).

Figure 21 shows the Sigma Naught (σ°) in dB after some colour manipulation and the histogram of the Sigma Naught (σ°) image.

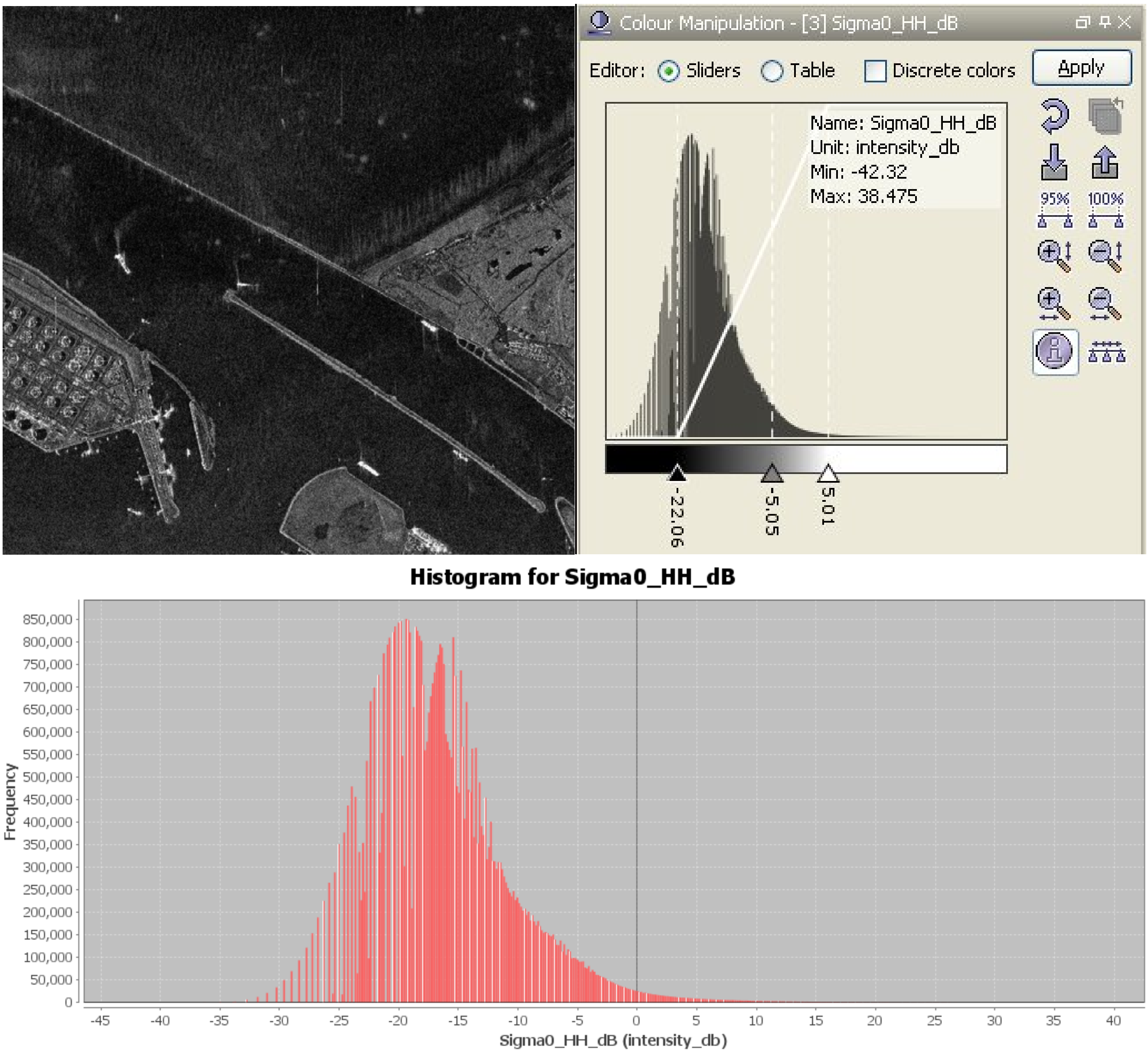

Figure 21 – TerraSAR-X-Spotlgiht image (28Feb.2011) - On the top left the Sigma Naught (σ°) after colour manipulation to enhance the targets and on the top right, the corresponding histogram. On the bottom, we can see the histogram of the image.

Table 5 gives the statistics of the Sigma Naught (σ°) TerraSAR-X-Spotlgiht image (28Feb.2011). The Sigma Naught (σ°) range from -42.320 dB up to 38.475 dB. The Mean value is -16.043 dB, the Median is -16.914 dB and the standard deviation is 5.838 dB.

Table 5 – Statistics of the TerraSAR-X-Spotlgiht image (28Feb.2011) (17:26 UTC)

Statistics	Values	Unit
Only ROI-Mask pixels considered: Number of pixels total: Number of considered pixels: Ratio of considered pixels:	No 53877048 53877048 100.0 %	
Minimum: Maximum:	-42.32041549682617 38.47500228881836	intensity_db intensity_db
Mean: Median: Std-Dev: Coefficient of Variation:	-16.043004126554912 -16.91404388844967 5.838443679025168 0.5677452336744626	intensity_db intensity_db intensity_db intensity_db

Checking the radar backscattering coefficient of the targets (boats) detected, we get values ranging from 4.550 dB up to 36.052 dB. The SAR signature of the boat deployed has 6.460 dB.The analysis of the Sigma Naught values (σ°) of the targets and the area around the targets shows a significant contrast.

5.6 – Summary of the Preliminary Analysis of the Spaceborne SAR Image and the Airborne Mini-SAR Swaths

This experiment involved one spaceborne SAR image TerraSAR-X-Spotlight, several Airborne Mini-SAR swaths and one boat. The boat deployed as target was detected in the spaceborne SAR image. The Airborne Mini-SAR swaths detected several boats and other small targets. Table 6 summarises the characteristics of the SAR image acquired and the targets detected.

Table 6 – List of spaceborne and airborne SAR Images acquired during the experiment and detected boats.

ROTTERDAM – THE NETHERLANDS				
Date / Time	**Place**	**Satellite / Mode**	**Ground Truth Data**	**Detected Boats**
28.Feb.2011 (PM)	**Rotterdam - Netherlands**	**TerraSAR-X / Spotlight**	**GPS/Photos/Movies**	**1 out of 1 deployed + Several Targets of opportunity**
01.Mar.2011	**Rotterdam - Netherlands**	**Mini-SAR Swaths**	**GPS/Photos/Movies**	**Several Targets of opportunity**

Table 7 gives the minimum and maximum Sigma Naught (σ°) of the targets detected in each SAR image.

Table 7 – Minimum and maximum Sigma Naught (σ°) of the targets detected in each SAR image.

Date /Time UTC (LT)/Pass	Satellite / Image Mode / Polarisation	Sigma Naught (σ°) Min / Max
28.Feb.2011/17:26:57 UTC/ ASC	**TerraSAR-X / Spotlight / HH**	**4.550dB / 36.052 dB**

The SAR signatures of the boats deployed were very weak. Some possible reasons to explain such weak signatures are the sea state, the wind speed, the incidence angle and the type and materials. Another possible reason is the processing at DLR.

6. – Preliminary Conclusions

The analysis of the results of this coupled UAS/Spaceborne SAR experiment shows a promising potential for the use of UAS for maritime surveillance. UAS can be integrated into the airborne building block of maritime surveillance systems to complement the existing assets, increase system performance and improve the overall maritime domain awareness. The main perceived maritime security and safety threats comprise piracy, terrorist and military threats, weapons proliferation/smuggling, drugs trafficking, illegal immigration, unlawful use of containers, attacks to critical infrastructures and illegal fishing. The main maritime security and safety gaps include a lack of technologies with the capability of detecting small targets (e.g. small boats), a lack of wide area and persistent maritime surveillance, a lack of coordination and information sharing, limited interoperability, a lack of containers security, a lack of persistent surveillance of critical infrastructures and early warning systems. Unmanned Aircraft Systems (UAS) are an emerging technology with strong potential to mitigate the above mentioned threats by filing in the main maritime security and safety gaps listed earlier. For instance, the wide range of potential applications of UAS to maritime surveillance includes, but is not limited to:

- — detection, classification and identification of small boats,
- — persistent maritime surveillance,
- — use as communications relays,
- — persistent surveillance of critical infrastructures,
- — early warning systems,
- — COMINT and ELINT collection, etc..

Table 11 illustrates the mapping of maritime security/safety threats vs gaps and summarises the main potential applications of UAS to maritime surveillance.

The above mentioned potential applications of UAS to the Maritime Domain will be addressed in turn in more detail next.

- — Detection, classification and identification of small boats – The capability of detecting, classifying and identifying small targets (e.g. small boats) is among the key technologies required to improve maritime domain awareness. This capability is critical to mitigate piracy, illegal immigration, drugs trafficking, weapons smuggling, illegal fishing, terrorism and critical infrastructure. Unmanned Aircraft Systems (UAS) provide this capability more efficiently and at a lower cost than any other existing technology.

- — Persistent maritime surveillance – With the continuous improvements of UAS technologies, such as platforms, sensors, collision avoidance systems, command and control systems, telecommunications, etc., UAS are increasing their autonomy, endurance and flexibility. These characteristics are very important for persistent maritime surveillance. UAS can be launched from land, ships, aircraft and technologies to launch UAS from submarines are currently under development. UAS have distinct advantages over other existing technologies for persistent maritime surveillance in terms of autonomy/endurance (the Global Surveyor has an autonomy of 1 week), cost (e.g. as the autonomy of UAS increases, the number of staff required to operate UAS decreases), risk (e.g. if the UAS crashes the crew is not at risk), flexibility (e.g. they can be launched from a ship reducing the time to reach potential threats), etc..

- — Communications relays – UAS are being used as communication relays, mainly in military context, but have the potential to play a similar role in Civil context in several situations, such as to replace satellite communications or as a redundant system over any location on Earth. The main advantages of using UAS as communication relays is that airborne communication relays mitigate kinetic and noise jamming threats to satellite communications uplinks by providing an alternative set of links either directly to surface-based terminals or to satellites beyond the range of threats. They are less susceptible to noise jamming threats than satellites because an adversary has to detect, geolocate and track the airborne asset and operate within line of sight of the receive antenna main beam.

- — Persistent surveillance of critical infrastructures – The security of critical infrastructures, such as nuclear power plants, refineries, ports, etc. requires persistent surveillance. UAS can play an important role in providing persistent surveillance over critical infrastructures and over a wide area around the critical infrastructure. Some advantages of UAS over other existing technologies, such as ground-based assets (e.g. video cameras, alarm systems, manned aircraft, etc.), comprise the security of the UAS (e.g. hardly can be damaged or switched off as any ground-based asset), the area covered by a UAS (e.g. it is larger than the area covered by any ground-based asset), the cost (e.g. UAS is cheaper than manned aircraft with similar capability), etc..

- — Early warning systems – UAS have the potential to be used as part of an integrated system of systems for early warning. A UAS can provide information about a given area at a fraction of the cost of alternative means. Formation flying of UAS can cover a wide maritime area. It is reasonable to assume that in a foreseeable future with the advent of UAS with increased autonomy, the operations cost of UAS will likely decrease, making them increasingly more attractive.

- — COMINT and ELINT collection – SIGNal INTelligence (SIGNINT) can be divided into two categories, namely COMINT and ELINT. COMINT stands for Communication Intelligence and ELINT for Electronic Intelligence. Collection of COMINT is passive. Exploitation of COMINT requires a human operator, which implies COMINT UAS are suitable for COMINT and ELINT collection in different scenarios,

The relatively reduced amount of data collected and analysed during this experiment and the lessons learned do not allow drawing final conclusions about the feasibility of using Unmanned Aerial Systems (UAS) for maritime surveillance. However, this experiment allowed hands-on experience with UAS technologies and significantly improved the awareness for its applications to maritime surveillance and related issues involved, including its potential, the feasibility, as well as the limiting and enabling factors. These different aspects will now be analysed in turn in the next sections.

Table 11 illustrates the mapping of the main maritime security threats and gaps, as well as the main priorities in terms of the different technologies involved in maritime surveillance. For each maritime threat, the technologies required to fill in each gap is indicated and its priority is expressed in a range of numbers (1 to 3, 1 = Maximum Priority, 2 = Medium Priority, 3 = Low Priority) and colours (Red = Maximum Priority, Orange = Medium Priority, Green = Low Priority). The main technologies involved in maritime surveillance are listed on the bottom of figure 4 and are reproduced here for convenience of the reader: 1.- Reporting Systems, 2.- Sensors, 3.- Platforms, 4.- Communications, 5.- Data Fusion & Sharing, 6.- Intelligence and 7.- Databases. For example, the mitigation of the main threat Piracy requires filling in several maritime security gaps (e.g. lack of persistent surveillance, lack of wide-are maritime surveillance, lack of small boat detection, lack of Early Warning Systems, and lack of Information Sharing with maximum priority (1- Red) and among the required technologies listed are UAS, LTAAV, GEO-HR, etc. Concerning the remaining two gaps (Limited Interoperability and Containers Security) they are less relevant to mitigate Piracy, hence the priority for Limited Interoperability is 2-Orange and for Containers Security is 3- Green.

Table 8 – The Main Maritime Security and Safety Threats vs Gaps and the technologies that can be used to mitigate them.

Maritime Security Main Threats / Gaps

Gaps→ / ↓ Threats	Lack of Risk Assessment Capability	Lack of Persistent Surveillance	Lack of Wide-Area surveillance	Lack of Small Boat Detection	Lack of Early Warning Systems	Lack of Information Sharing	Limited Interoperability	Lack of Containers Security
• Piracy	UAS, LTAV,GEO-HR + ...	UAS, LTAV,GEO-HR + ...	SAR, GEO-HR + ...	UAS, USV, LTAV + ...	UAS, LTAV, + ...	Coordination & Sharing + ...	Interoperabilty Optimisation + ...	
	1, 2, 3, 5, 6, 7	1, 2, 3, 5, 6 7	1, 2, 3 5, 6	1, 2,3	12,3,4,5,6	4,56,7	1,2,3,45,6,7	1,2,3,45,6,7
• Terrorism	UAS, LTAV,GEO-HR + ...	UAS, LTAV, GEO-HR + ...	SAR, AIS GEO-HR + ...	UAS, USV, LTAV + ...	Intelligence + ...	Inteligence + ...	Interoperabilty Optimisation + ...	Intelligence + ...
	1, 2, 3, 5, 6, 7	1, 2, 3, 5 6	1, 2, 3 5, 6	1, 2,3	12,3,4,5,6	4,56,7	1,2,3,45,6,7	1,2,3,45,6,7
• Weapons of Mass Destruction Smuggling	UAS, LTAV,GEO-HR + ...	UAS, LTAV,GEO-HR + ...	SAR, AIS + ...	UAS, USV, LTAV + ...	Intelligence + ...	Inteligence + ...	Intelligence + ...	Intelligence + ...
	1, 2, 3, 5, 6, 7	1, 2, 3, 5 6	1, 2, 3 5, 6	1, 2,3	12,3,4,5,6	4,56,7	1,2,3,45,6,7	1,2,3,45,6,7
• Drugs Trafficking	UAS, LTAV,GEO-HR + ...	UAS, LTAV,GEO-HR + ...	SAR, AIS + ...	UAS, USV, LTAV + ...	Intelligence + ...	Inteligence + ...	Intelligence + ...	Intelligence + ...
	1, 2, 3, 5, 6, 7	1, 2, 3, 5 6	1, 2, 3 5, 6	1, 2,3	12,3,4,5,6	4,56,7	1,2,3,45,6,7	1,2,3,45,6,7
• Illegal Immigration	UAS, LTAV,GEO-HR + ...	UAS, LTAV,GEO-HR + ...	SAR, AIS + ...	UAS, USV, LTAV + ...	Intelligence + ...	Inteligence + ...	Intelligence + ...	Intelligence + ...
	1, 2, 3, 5, 6, 7	1, 2, 3, 5 6	1, 2, 3 5, 6	1, 2,3	12,3,4,5,6	4,56,7	1,2,3,45,6,7	1,2,3,45,6,7
• Critical Infrastructure Security	UAS, LTAV,GEO-HR + ...	UAS, LTAV,GEO-HR + ...	SAR, AIS + ...	UAS, USV, LTAV + ...	+ ...	Inteligence + ...	Intelligence + ...	Intelligence + ...
	1, 2, 3, 5, 6, 7	1,2, 3, 6	1, 2, 3 5, 6	1, 2,3	12,3,4,5,6	4,56,7	1,2,3,45,6,7	1,2,3,45,6,7
• Illegal Fishing	UAS, LTAV,GEO-HR + ...	AIS+SAR, UAS,LTAV+ ...	SAR,AIS, GEO-HR+ ...	UAS, USV, LTAV + ...	Intelligence + ...	Inteligence + ...	Intelligence + ...	
	1, 2, 3, 5, 6, 7	1, 2, 3, 5 7	1, 2, 3 5, 6	1, 2,3	12,3,4,5,6	4,56,7	1,2,3,45,6,7	
• Unlawful Use of Containers (Security)	UAS, LTAV,GEO-HR + ...	GPS Tracking + ...			Intelligence + ...	Inteligence + ...		GPS, Intrusion Detection, Seal
	1, 2, 3, 5, 6, 7	4, 6, 7	1, 2, 3 5, 6	1, 2,3	12,3,4,5,6	4,56,7	1,2,3,45,6,7	1,2,3,45,6,7

(-)	Priority	(+)	Not Relevant

SURVEILLANCE TECHNOLOGIES	1.- Reporting Systems	2.-Sensors	3.-Platforms	4.- Communications	5.- Data Fusion & Sharing	6.-Intelligence	7.-Databases

6.1 – Hands-on experience with UAS technologies and its applications to maritime surveillance

This coupled Airborne Mini-SAR / Spaceborne SAR campaign was a unique opportunity to acquire hands–on experience with Airborne SAR technologies and learn about the main issues related to its applications to maritime surveillance. From the planning phase up to the execution of the Mini-SAR flight there are several factors that need to be carefully analysed and taken into account. A summary of the main issues identified in this experiment is given next.

1.- Selection of the Experiment Area /Authorisation to Fly – This experiment was initially planned to use a UAS. Due to technical problems the UAS was replaced by a light aircraft (Cessna). However, the small aircraft has many similarities with the UAS. Apart the permission to fly, which is far more difficult for UAS, the operational side of maritime surveillance has many similarities. The Mini-SAR used in this experiment is very light (about 20Kg), so it can be easily carried by UAS as part of its payload. For the time being UAS can only be flown in restricted areas usually under control of national authorities, often the military. This is due to the risks that a UAS can pose to human life and property.

2.- UAS Communications Issues – Most UAS are not equipped with a Satcom antenna. Hence, most UAS can only fly in Line-Of-Sight (LOS) operation. To be able to fly Beyond Line-of-Sight (BLOS) Satellite communications are needed.

3.- Synthetic Aperture Radar (SAR) – A SAR sensor is essential for maritime surveillance since it allows day and night (24 / 7) operations regardless of weather conditions. The main limiting factor that can prevent the UAS from flying is the wind speed.

4.- Automatic Identification System (AIS) Receiver – An AIS receiver is a very important technology for maritime surveillance. Most UAS in use are not equipped with an AIS receiver. For maritime surveillance operations an AIS receiver is a very important tool since it allows the automatic identification of most ships allowing the UAS to concentrate on non-identified ships.

6.2 – Potential of UAS for Maritime Surveillance

UAS technologies are relatively recent and involve a wide range of fields spanning from aeronautics and sensors technologies to satellite communications and other engineering disciplines. Innovations in each of the fields involved are emerging by the day. UAS still have a long way to go before they become mature and their use fully operational. For the time being UAS are mainly used for military applications. However, a large number of non-military UAS applications have been identified by stakeholders and there are several studies and demonstration flights foreseen for the near future.

Maritime surveillance is one of the most challenging and promising fields of application of UAS. The challenges are due to the very demanding conditions under which the UAS must operate over sea and the requirements for safe operation.

The present UAS experiment has unveiled some of the potential of UAS for maritime surveillance. The UAS tests performed during this experiment include:

1 – Detection of a Small rubber Boat and a Fishing Ship,
2 – Tracking of a Small Boat and a Fishing Ship,
3 – Classification of a Small Boat and a Fishing Ship,
4 – Identification of a Small Boat and a Fishing Ship,
5 – Detection and Tracking of People on the Beach,

Despite the operational requirement that prevented the UAS from flying bellow 3km, the experiment has confirmed the capability of UAS for small boat detection, tracking and classification, as well as the capability for people detection and tracking. Concerning the identification of the targets, the characteristics of the images acquired during this mission suggest that flying at lower altitudes the UAS images would allow the identification of the targets. The UAS images can be seen from Figure 15 to 20.

6.2.1 – Advantages of UAS for maritime Surveillance

Some of the advantages of using UAS for maritime surveillance have been described in the literature and are summarized bellow.

- 1.- One potential benefit of UAS is that they could fill in a gap in current maritime surveillance by improving coverage.
- 2.- The range of UAS is a significant asset when compared to border agents on patrol or stationary surveillance equipment.
- 3.- Eletro-Optical InfraRed (EOIR) sensors (cameras) can identify small size objects from very high altitudes (high resolution).
- 4.- UAS can provide precise and near-real-time imagery to a ground control operator, who would then disseminate that information so that informed decisions regarding the deployment of border patrol agents can be made quickly.
- 5.- Long endurance UAS used along the border can fly for more than 30 hours up to several days without having to refuel, compared with manned helicopter's average flight time of just over 2 hours.
- 6.- The ability of UAS to loiter for prolonged periods of time has important operational advantages over manned aircraft.
- 7.- The longer flight times of UAS means that sustained coverage over a previously exposed area may improve maritime security.
- 8.- The range of UAVs is a significant asset when compared to border agents on patrol or stationary surveillance equipment. Nevertheless, the extended range and endurance of UAVs may lessen the burdens on human resources at the borders.
- 9.- UAS accidents do not risk the lives of pilots, as do the helicopters and aircraft currently used by Coast Guards for border patrolling.

6.2.2 – Possible Drawbacks of using UAS for maritime Surveillance

UAS also have disadvantages; some of them are briefly described next.

● 1.- There have been concerns regarding the high accident rate of UAS, which can be multiple times higher than that of manned aircraft. Because UAS technology is still evolving, there is less redundancy built into the operating system of UAS than of manned aircraft and until redundant systems are perfected mishap rates are expected to remain high.

● 2.- If control systems fail in a manned aircraft, a well-trained pilot is better positioned to find the source of the problem because of his/her physical proximity. If a UAS encountered a similar system failure, or if a UAS landing was attempted during difficult weather conditions, the ground control pilot would be at a disadvantage because he or she is removed from the event. Unlike a manned pilot, the remote pilot would not be able to assess important sensory information such as wind speed.

● 3.- Inclement weather conditions can also impinge on a UAS surveillance capability, especially UAS equipped with only an EO camera and Forward Looking Infrared Radar (FLIR), because cloudy conditions and high humidity climates can distort the imagery produced by EO and FLIR equipment. The effects of extreme climatic or atmospheric conditions on sensors reportedly can be mitigated with the outfit of one synthetic aperture radar (SAR) system and a moving target indicator (MTI) radar. However, adding SAR and MTI to a UAS platform would increase the costs associated with using UAS.

● 4.- Depending on the type of UAS, the costs of operating a UAS can be higher than the costs of operating a manned aircraft. This is because some types of UAS require a significant amount of logistical support and specialized operator and maintenance training. Operating one UAS may require a crew of up to 20 support personnel. The high comparative costs of operating some sophisticated types of UAS may be offset somewhat by their comparatively lower unit costs.

6.3 – Main Limiting Factors Preventing the Use of UAS

Several pre-requisites must be satisfied to render the UAS a viable, cost-effective and regulated alternative to existing resources. Major civil and commercial market barriers include:

- — Single European Sky
- — Sense and Avoid technologies
- — Command and Control Technologies Reliability
- — Communications (Bandwidth, LOS, BLOS)
- — Lack of airspace regulation that covers all types of UAV systems (encompassing ‘sense and avoid’, airspace integration and airworthiness issues)
- — Affordability - price and customization issues (e.g. commercial off-the-shelf, open modular architecture)
- — Lack of efforts to establish joint customer requirements (although this is gradually changing)
- — Liability for civil operation
- — Capacity for payload flexibility
- — Lack of sufficient secure non-military frequencies for civil operation
- — Perceived reliability (e.g. vehicle attrition rate vs. manned aircraft)
- — Operator training issues
- — Recognition/customer perception of the UAV market
- — Technology developments for multi-mission capability

6.4 – UAS Key Enabling Technologies

Figure 22 illustrates the components of a typical UAV System, showing some of the capabilities needed and the enabling technologies required for performing a given mission. Any UAV mission involves many capabilities and technologies. Due to the depicted system complexity the main key players, such as the US Department of Defense (DoD) and other agencies have started to use the term Unmanned Aerial System (UAS) in place of UAV.

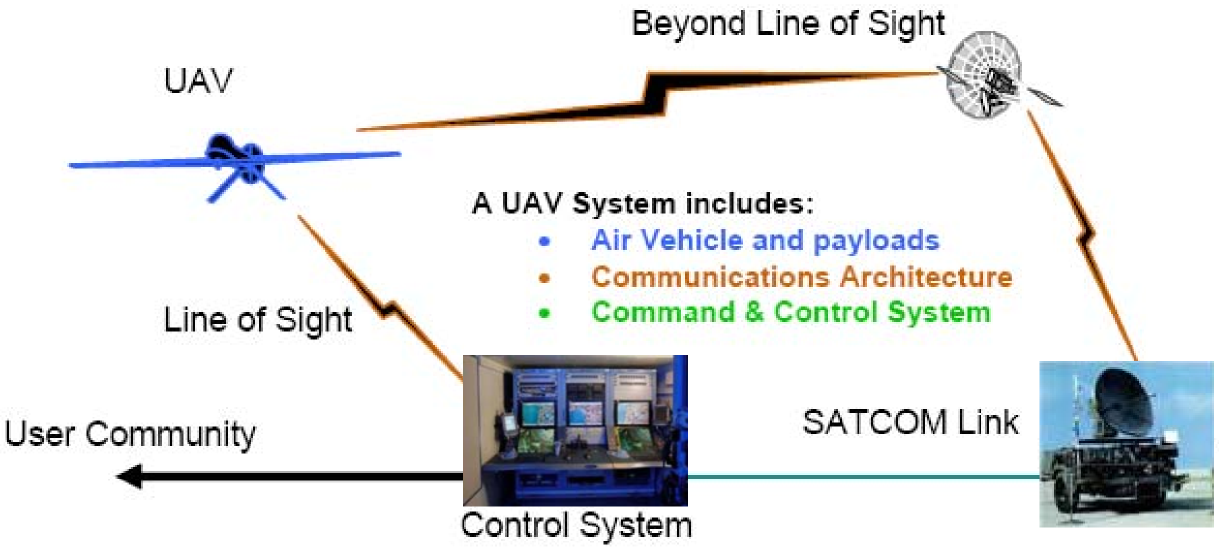

Figure 22 – Unmanned Aerial Vehicle System. Enabled by: Autonomous Mission Management, Reliable Flight Systems, Navigation Accurate Systems, Terrain Avoidance, Power and Propulsion

Some UAS key enabling technologies are listed below.

- — Autonomous Mission Management
- — Collision Avoidance
- — Intelligent System Health Monitoring
- — Reliable Flight Systems
- — Sophisticated Contingency Management
- — Intelligent Data Handling and Processing
- — Over-the-Horizon Communication
- — Network-Centric Communication
- — Open Architecture
- — Power and Propulsion
- — Navigation Accurate System Technology
- — Enhanced Structures

Table 9 gives a more detailed description of other critical technologies for emerging autonomous UAV systems both civil and military. Most of the technologies mentioned in Table 12 apply both to civil and military UAV systems.

Table 9 – Key Enabling Technologies (from SG/75 study on autonomous systems).

Critical Technologies	
Decision Making Software: • Fuzzy-based decision making • Knowledge-based system • Case-based reasoning • Self-learning techniques • Decision tree evaluation • Reasoning/Inferring • Probabilistic/stochastic reasoning Prediction Algorithms: • Predictive path/intent algorithms • Short reaction algorithm • Effectiveness evaluation Status Assessment Software: • Internal status analysis • Self-orientation Situation Analysis Software: • Situation analysis • Environmental analysis • External status analysis Modelling Software: • Air vehicle modelling algorithms • Sensor modelling algorithms • Scenario generation • Threat system modeling • Attack simulation • Mission success optimisation model • Simulation	Sensor Processing Software: • Sensor fusion • Area of interest identification • Automatic target recognition Adaptive and Self-learning Systems: • Failure self-compensation Attack Planning Software: • Attack plans and tactical alternatives • Plan change impact identification Weapon Engagement Procedure Software: • Weapon engagement algorithms Mission Plan Update Software: • Route planning system • Payload plan management system • Mission Success Optimisation model Path Optimisation Software: • Optimal trajectory planning • Path Optimisation System Targeting Software: • Target tracking • Target prioritisation Platform Technologies: • Obstacle detection and avoidance (airborne) • Obstacle detection and avoidance (ground) • Improved autopilot • Speech recognition

Figure 24 summarises system element designs needed to transition from current to next-generation autonomous UAV systems for civilian and military UAS.

Platforms	• Unreliable	• Safe, reliable
	• Short duration	• Long endurance
	• Vulnerable	• Survivable
	• Restricted airspace	• Controlled airspace
	• Single mission	• Multi-mission
Payloads	• Sensors only	• Weapons and sensors
Onboard Processing	• Vehicle and payload management	• Mission and contingency management
	• Signal processing	• Data Fusion; ATR
Communications	• Stovepipe	• Interoperable, net capable
	• Jam resistant	• Robust; secure; anti-jam
Mission Control	• Operator intensive	• Autonomous; intuitive HSI
	• Pre-planned	• Adaptive
	• Single vehicle	• Coordinated multi-vehicle
Support and Training	• Unique	• Common autonomic logistics

Figure 23 – System Element Designs Needed to Transition from Current to Next-Generation Autonomous UAV Systems.

These new paradigms are a combination of system attributes and technological capabilities. For instance, the data fusion, secure anti-jam, and coordinated multi-vehicle control require technological development as well as specific system development to bring full maturity to unmanned systems.

Finally, very small Micro UAVs (MAVs) and relatively large, sophisticated UCAV systems are examples of the range of UAVs that are applying the new platforms, payloads, onboard processing, communications, etc. to create next generation automated UAVs. It is with these new platforms, payloads, etc. that both UCAVs and MAV will be able to address similar operational challenges including:

- — **Mixed operation with other assets**:
  - Deconfliction, collision avoidance, C4I integration.
- — **Operation over populated areas**:
  - Safety issues.
- — **Need to reduce reliance on communications**:
  - UCAV – countermeasures.
  - MAV – limited size and power.
  - Limited line of sight environment.
- — **Need a fully integrated system**:
  - MAV propulsion/power generation still critical.
  - Operator machine interface critical.
  - All weather operations.
  - Survivability.

6.5 – Mission Readiness

6.5.1 – Mission Readiness Summary

This section summarises civil UAV mission readiness. The purpose of Mission Readiness is to assess the readiness status of the different technologies involved in UAS. In the present case this civil UAV mission readiness based on technology maturation forecasts that meet or exceed the desired, or required, capabilities identified by the user community.

Figure 25 summarises the mission readiness time forecasts for the different technologies. The technologies annotated with an asterisk (*) are shown within the figure with maturation forecasts based on development targets expressed in the US Department of Defences' UAV Roadmap document.

The purpose of the chart is to be able to identify when the capability to fly a particular mission can be expected as a function of time. The left-most end is the least probable and the right end the most probable timeframe.

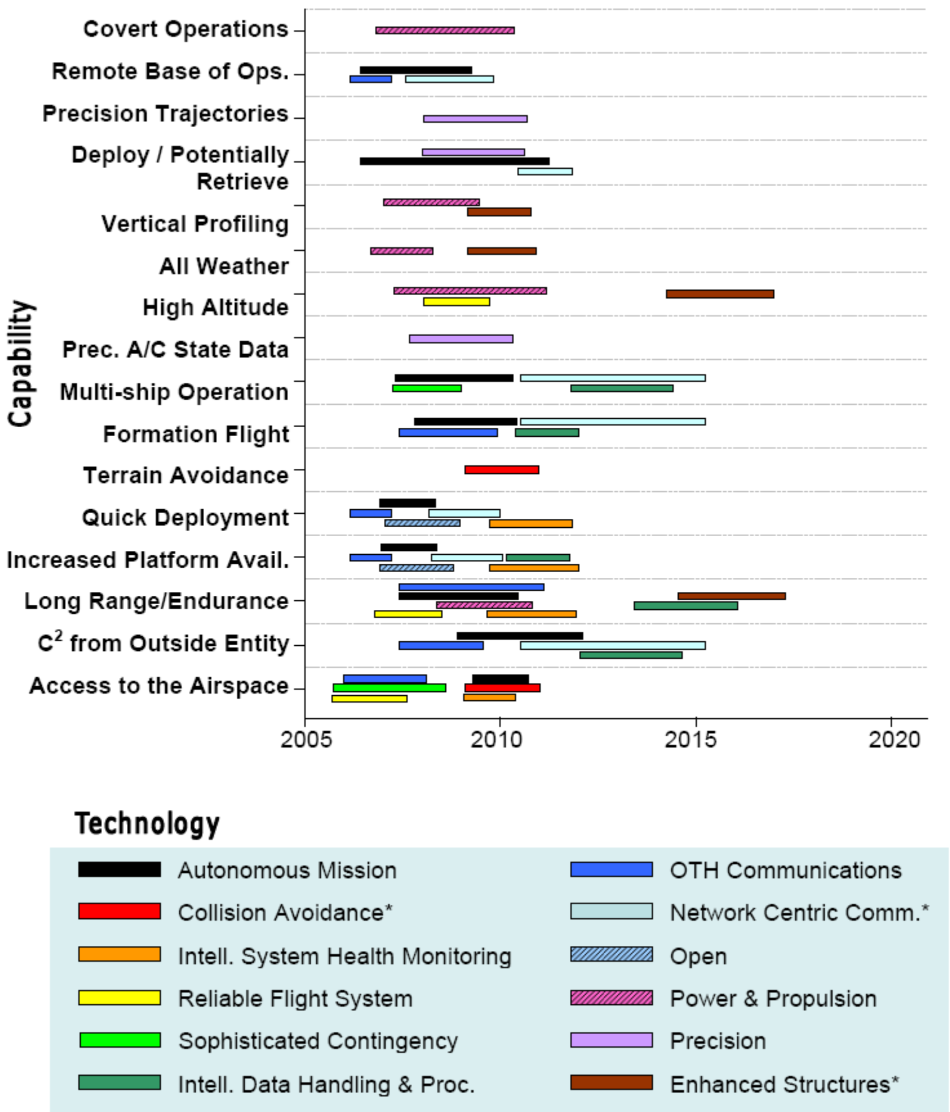

Figure 24 - Technology Maturation Summaries in Terms of Mission-Derived Capabilities.

6.6 – Small Boat Detection in SAR Satellite Imagery

The use of spaceborne SAR imagery for small boat detection requires additional small boat detection experiments under different conditions using different methods. It is not possible to draw final conclusions based on a limited number of small boat detection experiments, which are not representative of the multiple possible scenarios.

6.7 – Limitations of current State-of-the-Art SAR Satellite technology

The main limitations of current State-of-the-Art spaceborne SAR imagery for maritime surveillance, in particular aimed at small boat detection, are:

1. - SAR satellites repeat cycles do not allow the coverage of the same area at the required time intervals. Constellations of SAR satellites could be a solution.

2. - The conflict between resolution and image swath. High resolution is required to detect small boats. However, the high resolution images have small swaths. Maritime surveillance with high resolution images would require a large number of images to cover wide maritime areas, which is very expensive and for the time being technically not feasible. Intelligence data can play an important role by indicating an approximate position of suspicious non cooperative targets, therefore reducing the surveillance area, which can then be imaged using high resolution images.

3.- Spaceborne high resolution SAR imagery acquisition times are long enough to allow significant motion of the target during the acquisition time degrading the quality of the image. Further research efforts are needed to develop new sensors and platforms. As far as sensors are concerned, shorter integration times are needed to prevent the blurring effect caused by the motion of the targets. Regarding the platforms, more platforms are needed to allow lower repeat cycles and improved coverage.

7. – Plans for Future Work

The maritime surveillance controlled experiments carried out by the EC-JRC together with third parties (e.g. Member States, EU Agencies, Industry, etc.), include:

1.- A Small Boat detection controlled experiment in Sardinia, Italy with Frontex and the Italian Authorities (Sep. 2009);
2.- A Small Boat detection controlled campaign in Palomares Canyon, Spain with Frontex and the Spanish Authorities (Oct.2009);
3.- A Small Boat detection controlled trial in the Algarve, Portugal (Dec.2009).
4.- A Small Boat detection controlled campaign in Portoroz, Slovenia with the University of Slovenia (May./Jun. 2010).
5.- A Coupled Spaceborne SAR/UAS Small Boat detection experiment in Sardinia with Alenia Aeronautica (Oct.2010).
6.- A Coupled Spaceborne SAR/UAS Small Boat detection experiment in Haifa, Israel with Elbit Systems (Dec.2010).
7.- A Spaceborne SAR Small Boat detection controlled campaign in the South of Spain and in Portugal (Dec.2010).
8.- A Coupled Spaceborne SAR / Airborne Mini-SAR Small Boat detection controlled experiment in Rotterdam, The Netherlands, with Metasensing (May./Jun. 2011).
9.- A Maritime Surveillance UAS controlled experiment within the WIMAAS framework in Huelva, Spain, (Jul.2011).

These maritime surveillance controlled experiments allowed a significant hands-on experience with key maritime surveillance technologies, including spaceborne SAR and UAS. The EC-JRC built an important knowledge about the Concepts of Use (CONUSE) and Concepts of Operations (CONOPS) of spaceborne SAR and UAS technologies, as well as the main issues related to their use for maritime surveillance. Spaceborne SAR and UAS are complementary technologies for maritime surveillance since UAS can fill in existing maritime surveillance gaps between ground-based/ship-borne assets and spaceborne SAR, such as the detection, classification and identification of small targets (e.g. small boats). Under suitable conditions of sea state and wind speed, spaceborne SAR can be used to detect small boats. However, the classification and identification of small boats can not be done using spaceborne SAR. UAS has a strong potential to fill in that maritime surveillance gap because it allows classification and identification of small boats.

The small boat detection trials carried out by the JRC were very successful since most small boats deployed during the experiments were detected in different sea states, wind speeds and geographical locations. The several small boat detection campaigns conducted by the EC-JRC seem to suggest that the probability of detection of small boats in spaceborne SAR images strongly depends on factors, such as the sea state, the wind speed, the type of boat (shape and materials), the weather conditions, etc.. The results of the experiments conducted thus far are no enough to draw final conclusions about the feasibility of using spaceborne SAR imagery for small boat detection. However, the experiments have an overall positive outcome because they indicate that under suitable sea state and wind speed conditions it is possible to detect small boats using spaceborne SAR. The estimation of the probability of detection of small boats in spaceborne SAR images requires a large number of experiments under different circumstances (e.g. sea state, wind speed, characteristics of the targets, image type and mode, etc.).

Future plans include additional Coupled spaceborne SAR / UAS experiments to further assess the potential of these technologies for maritime surveillance.

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Abstract

The European maritime area is one of Europe's most important assets with regard to resources, security and ultimately prosperity of the Member States. A significant part of Europe's economy relies directly or indirectly on it. It is not just the shipping or fisheries industries and their related activities. It is also shipbuilding and ports, marine equipment and offshore energy, maritime and coastal tourism, aquaculture, submarine telecommunications, blue biotech and the protection of the marine environment. The European maritime area faces several risks and threats posed by unlawful activities, such as drugs trafficking, smuggling, illegal immigration, organised crime and terrorism. Piracy in international waters also constitutes a threat to Europe since it can disrupt the maritime transport chain. These risks and threats can endanger human lives, marine resources and the environment, as well as significantly disrupt the transport chain and global and local security. It is anticipated that these risks and threats will endure in the mid and long run. In order to keep Europe as a world leader in the global maritime economy, an effective integrated/interoperable, sustainable maritime surveillance system and situational awareness are needed.

A significant number of unlawful maritime activities, such as illegal immigration, drugs trafficking, smuggling, piracy and terrorism involve mainly small boats, because small boats are faster and more difficult to detect using conventional means. Hence, it is very important to find out the feasibility of using new sensors and platforms, such as SAR or Unmanned Aerial Systems (UAS) for small boat detection, tracking, classification and identification, as well as to study the potential of airborne SAR for maritime surveillance. Since 2010 the EC-JRC has carried out a number of coupled UAS and spaceborne SAR maritime surveillance campaigns to assess the potential of UAS for maritime surveillance, in particular for small boat detection. This report presents the results and conclusions of the JRC – Metasensing Coupled Spaceborne SAR and Airborne SAR campaign carried out in Feb. 2011 in Rotterdam, The Netherlands.

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